National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Regressions in AIRS v5 Retrieval

Evan Manning

Sung-Yung Lee

California Institute of Technology
Jet Propulsion Laboratory

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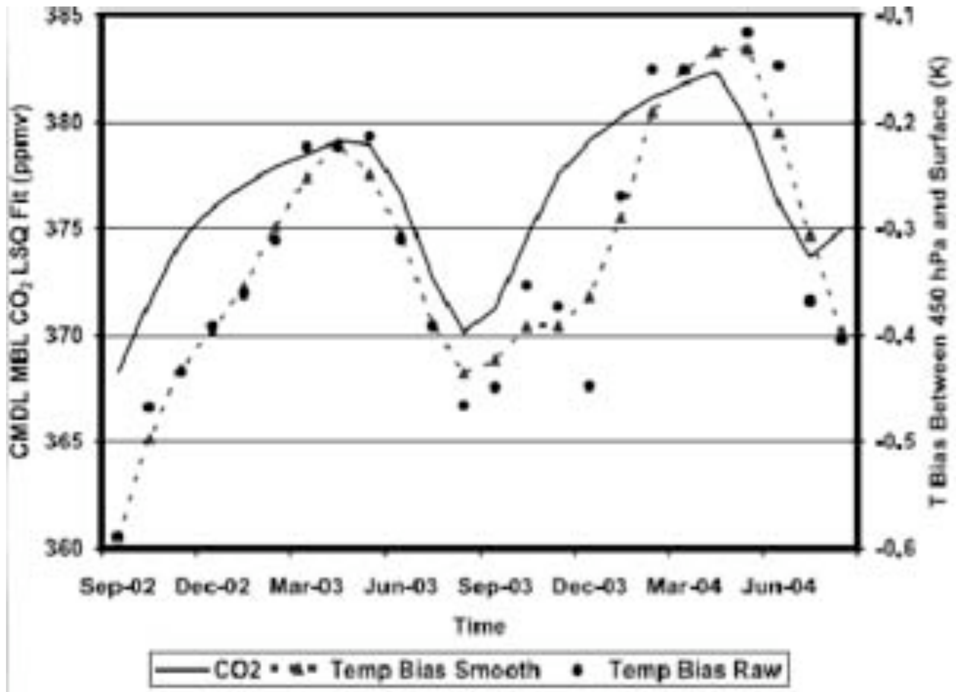
This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology under a contract with the National Aeronautics and Space Administration.

Summary

- **Murty Divakarla of NOAA and Thomas Hearty of NASA have shown spurious trends ~100 mK/yr in version 4 & 5 AIRS retrievals vs. truth**
- **Evidence points to regression retrieval steps as a major source of these**
- **Version 6 AIRS retrievals will reduce reliance on regressions and improve practices where regressions are retained**

From Divakarla -- Apparent Trend in AIRS v4 vs. Radiosonde

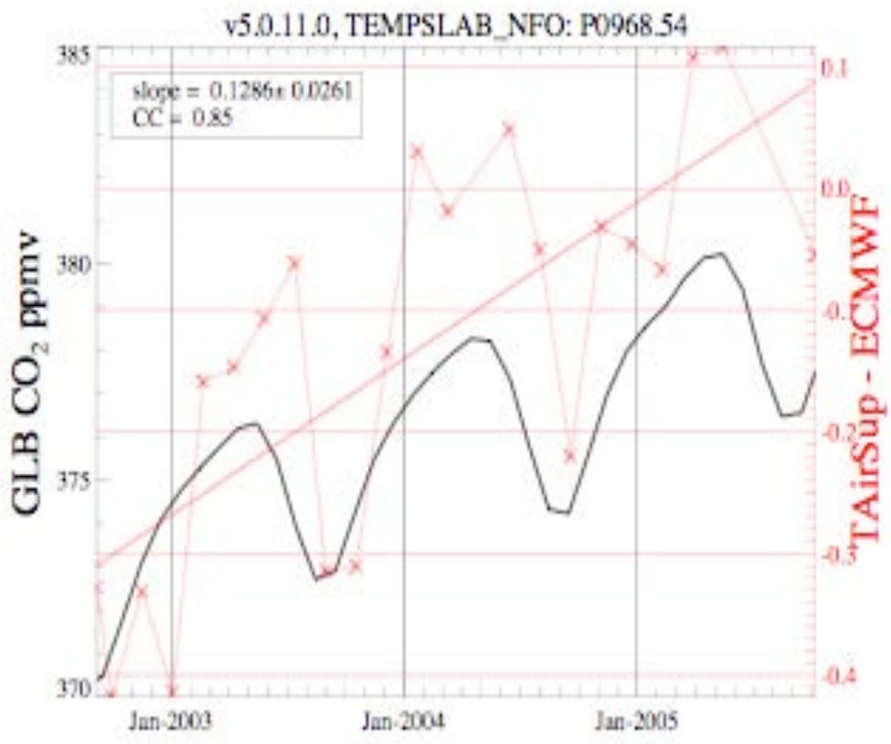
- **Divakarla et al 2006**
- **Correlated with CO_2**
- **AIRS version 4**
- **AIRS version 5 added changing CO_2 background in physical retrieval**

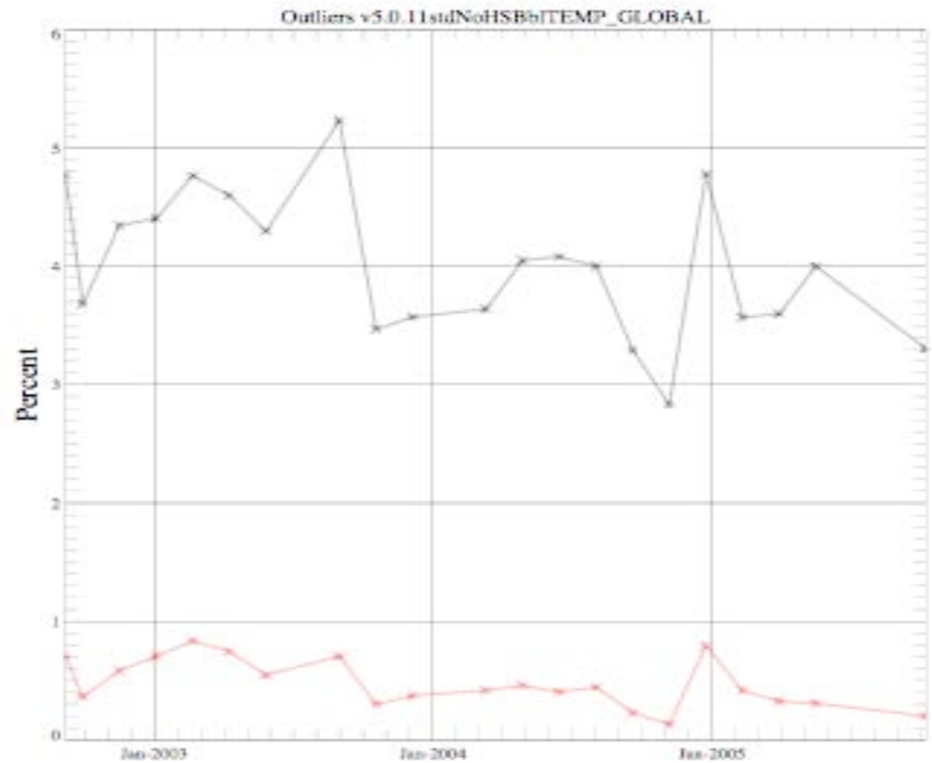


igure 14. Seasonal trends between AIRS retrieval bias 150 hPa to surface and CMDL MBL CO_2, 90°N–90°S. Average differences between RAOB and AIRS temperatures are indicated by solid circles, smoothed differences using a 2-month sliding boxcar average are indicated by the dashed line, and zonally weighted linear least squares fit for the CMDL MBL product are indicated by the solid line.

From Hearty - Trend in V5 Global Temperature

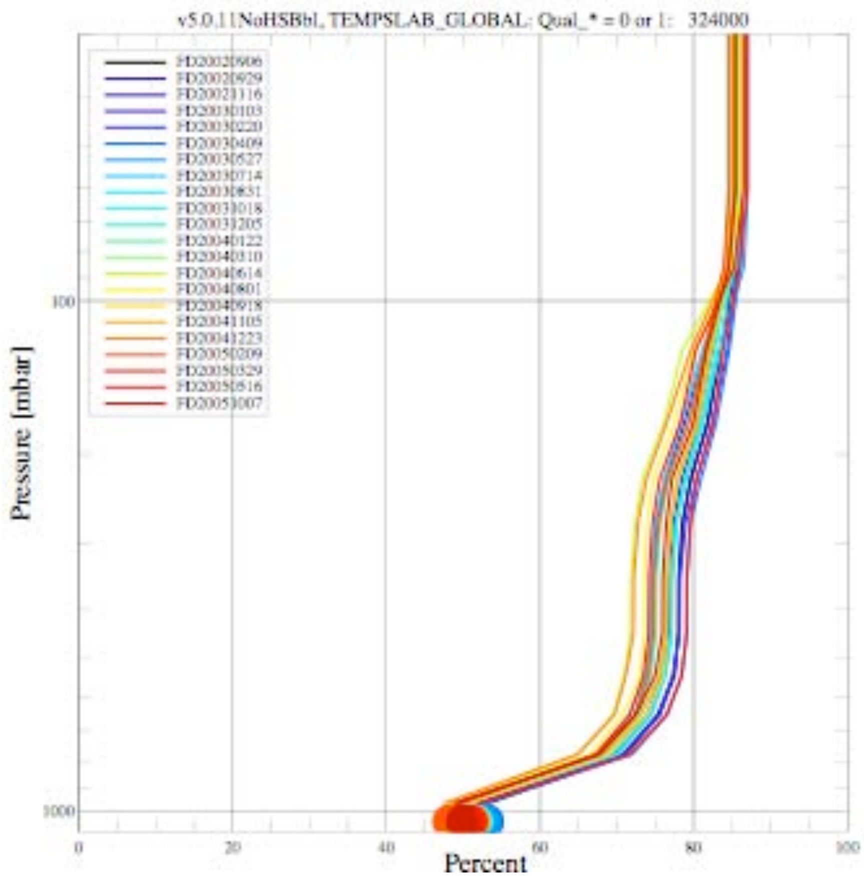
- **Upward trend in temperature bias vs. ECMWF**
- **Downward trend in outliers**

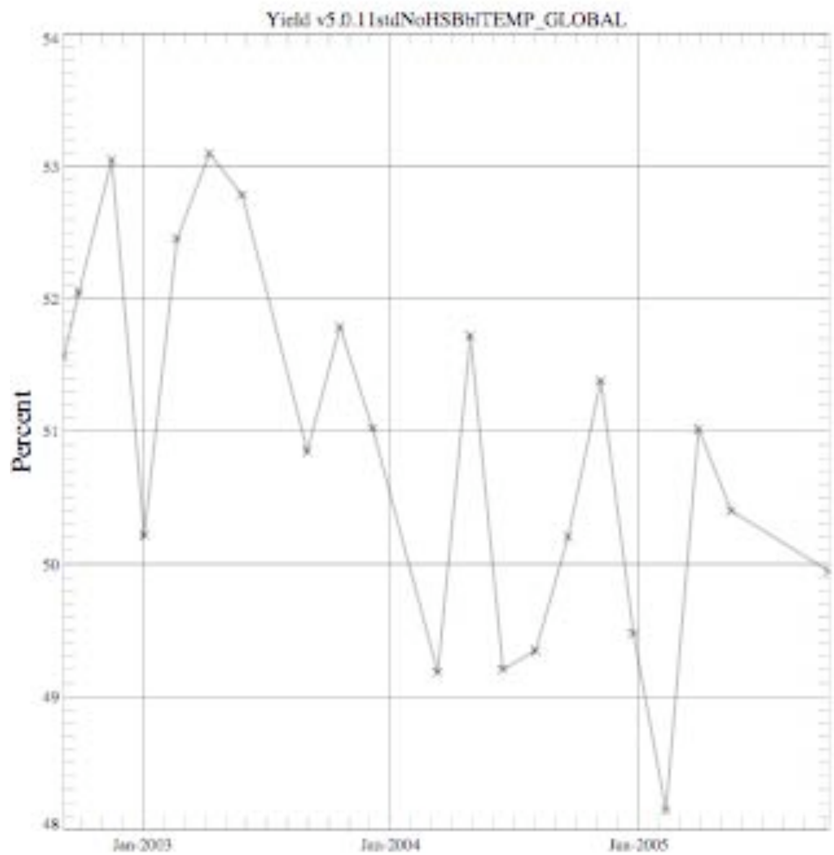




- Black line are mild outliers
- Red line are extreme outliers

From Hearty - Trend in V5 Global Temperature Yield





Much more in Hearty presentation in http://airs.jpl.nasa.gov/Science/ResearcherResources/MeetingArchives/TeamMeeting20070327/

Temporal Variation in Local Angle Adjustment

Background:

- AIRS v5 retrievals are performed over a 3x3 array of FOVs, assuming all differences among the 9 FOVs are due to clouds

- Because of the instrument scan pattern, these 9 FOVs are observed at 3 different angles through the atmosphere, introducing small differences in the spectra

- Local angle adjustment makes small changes to the spectra from the outer 6 FOVs to emulate what would have been seen at the central angle

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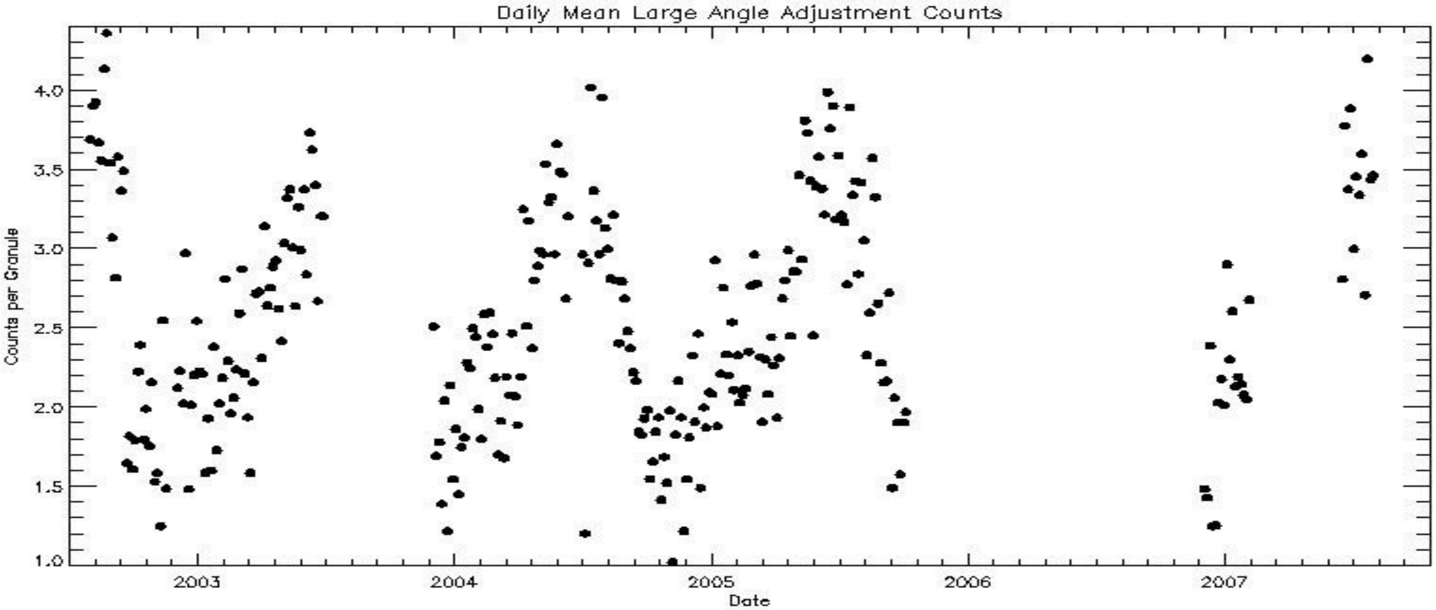
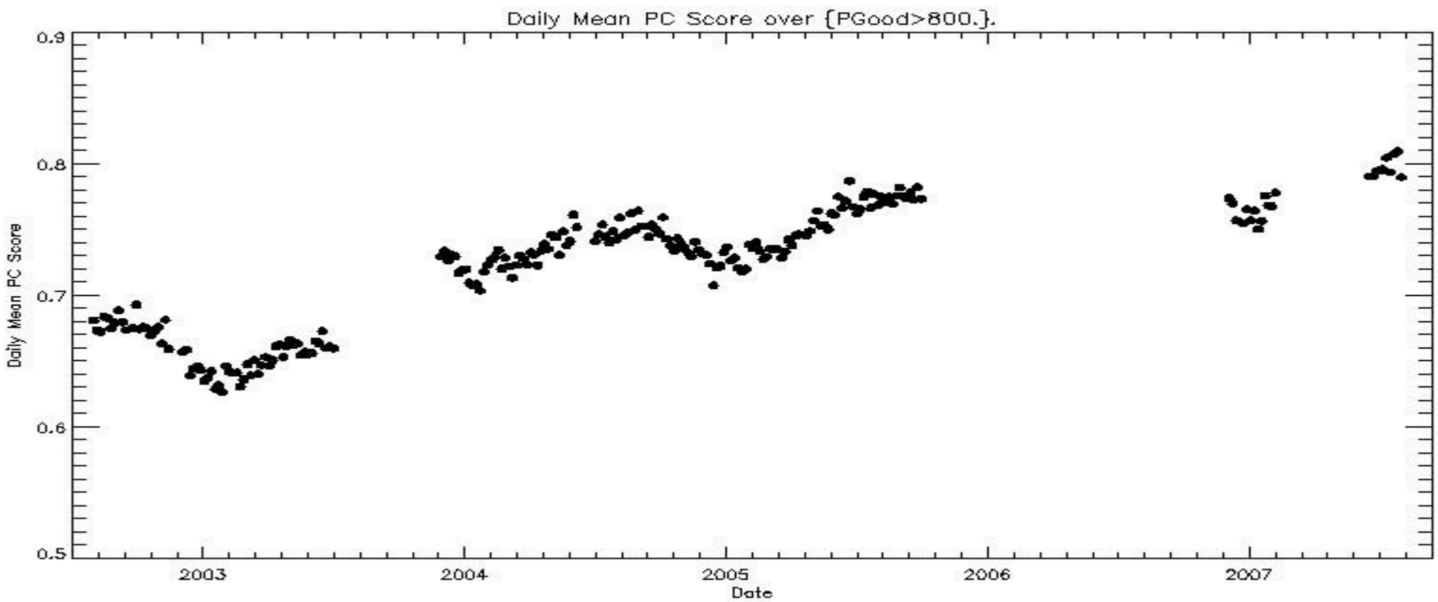
Temporal Variation in Local Angle Adjustment

- **Each 6-minute granule produces a count of number of FOVs with "big" angle adjustments (at least 5 channels adjusted by at least 20 * noise)**
- **The number of these cases shows a strong annual cycle**
- **But remember, LAA is a small adjustment (generally)**



Temporal Variation in PC Scores

- **Lower PC score means the input matches the training set better**
- **PC Scores are rising with time**
- **There is a clear seasonal cycle**
- **PC Scores are used in quality control -- higher PC scores mean more rejections.**



Daily Mean of PC Scores where Pgood > 800 mbar

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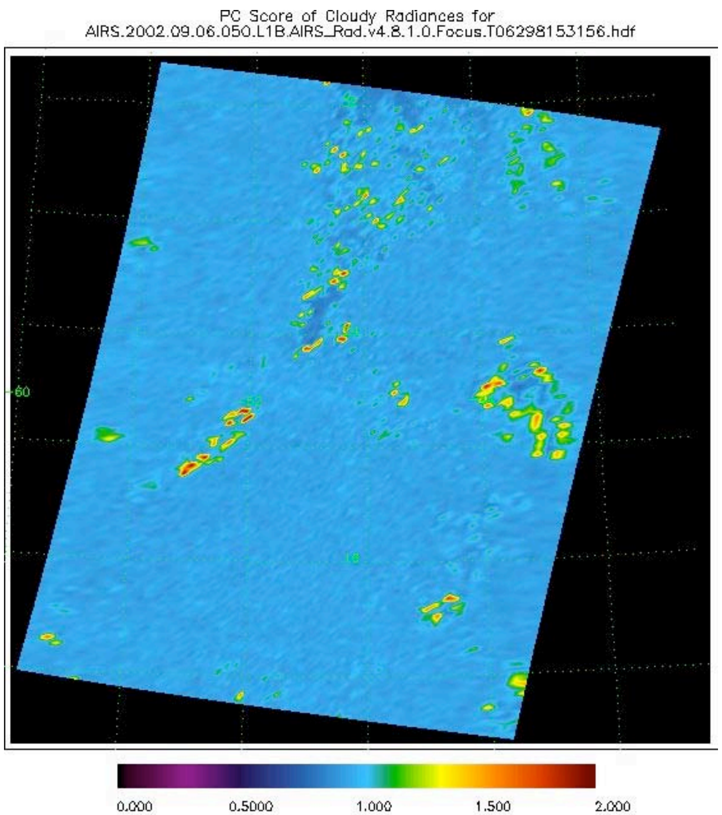
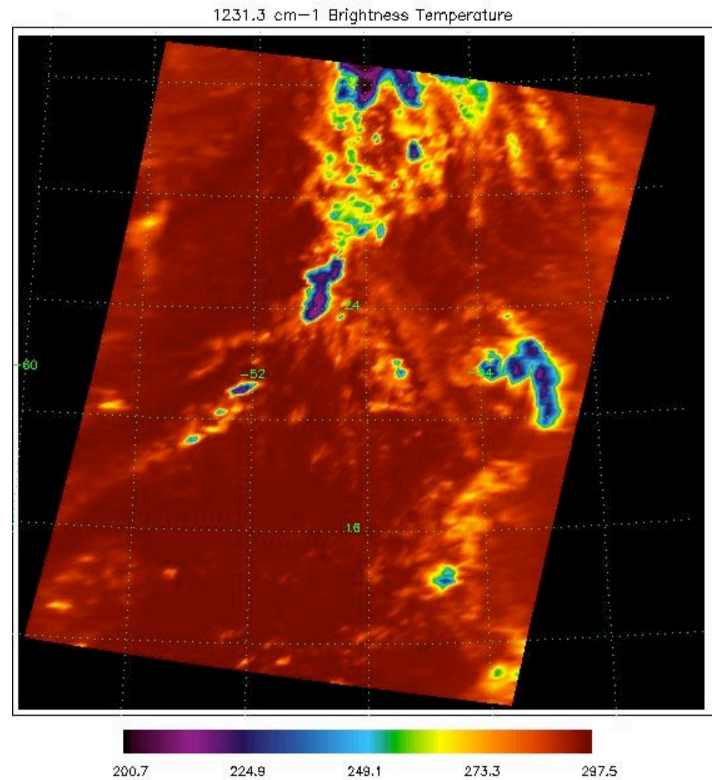
Why Suspect Regressions?

- **Regressions occupy key points in the retrieval**
- **Regressions have a known dependency on training data -- they only know how to handle what they have seen before**
  - These regressions use a large number (~50%) of all 2378 AIRS channels. When any channel is unavailable, it must be filled somehow.
  - PC Scores are consistently elevated in regions of fires, dust, edges of clouds, sun glint, SO_2, etc.
  - Regressions are trained with a narrow range of background CO_2 will have trouble with later data with more CO_2

Difficult Cases for Regression -- Edges of Clouds

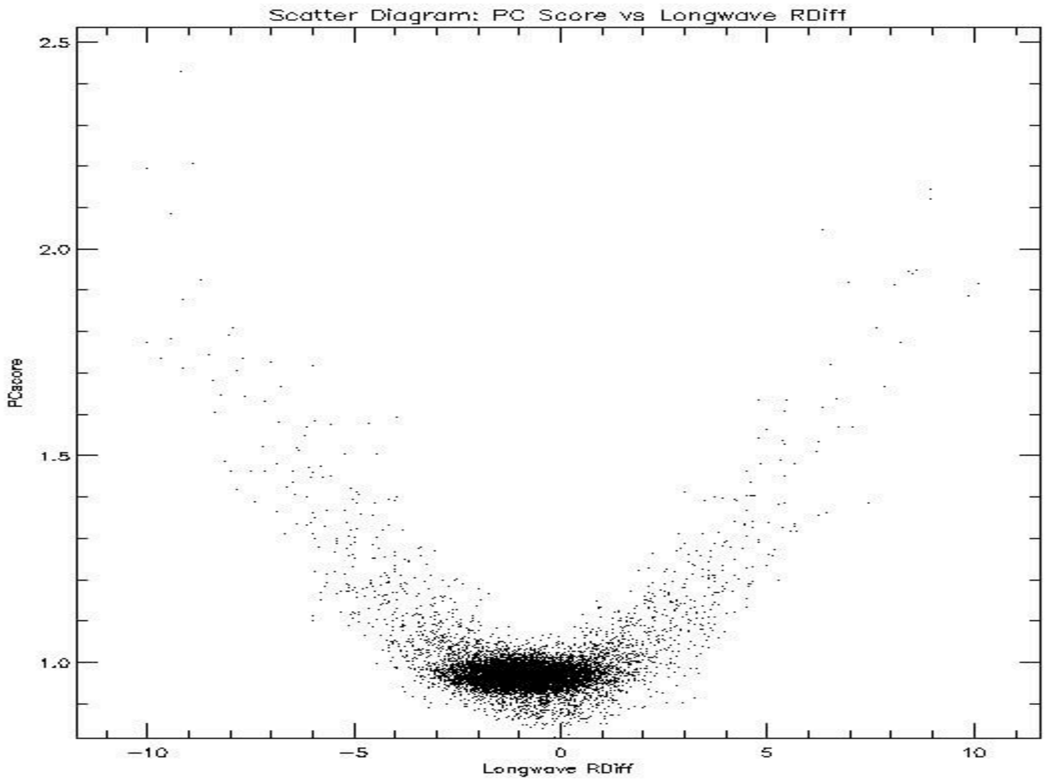




PC Score **Granule 50 of Sept 6, 2002** Tb 1231 cm^{-1}

High value of PC score is correlated with side of cloud, where C_{ij} tends to be high

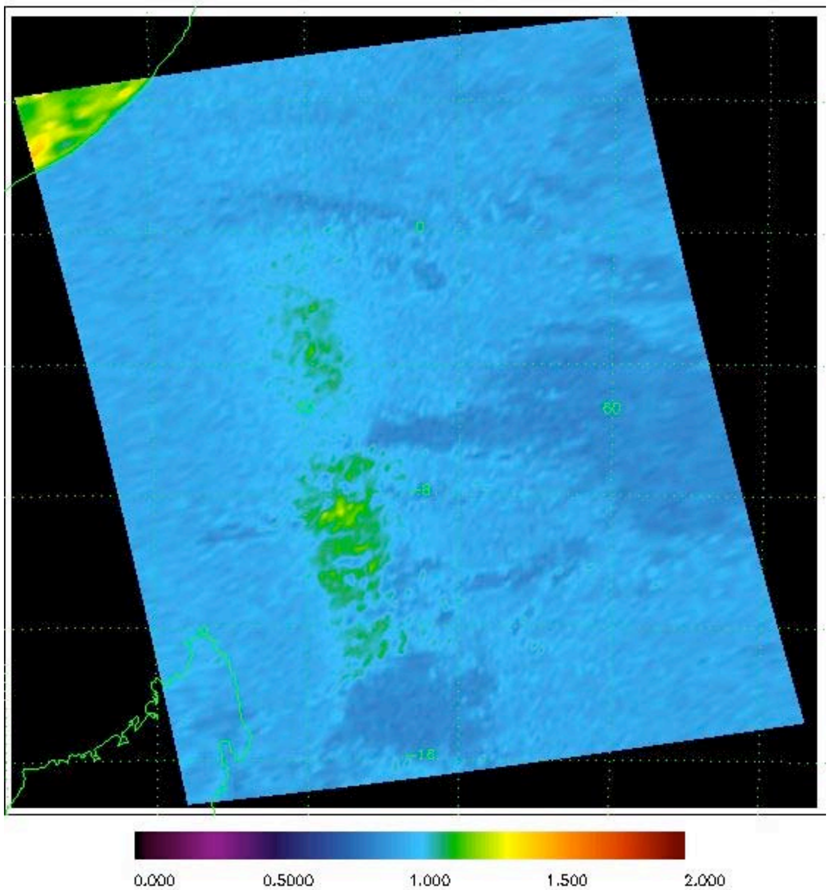
Difficult Cases for Regression -- Edges of Clouds (Cont)



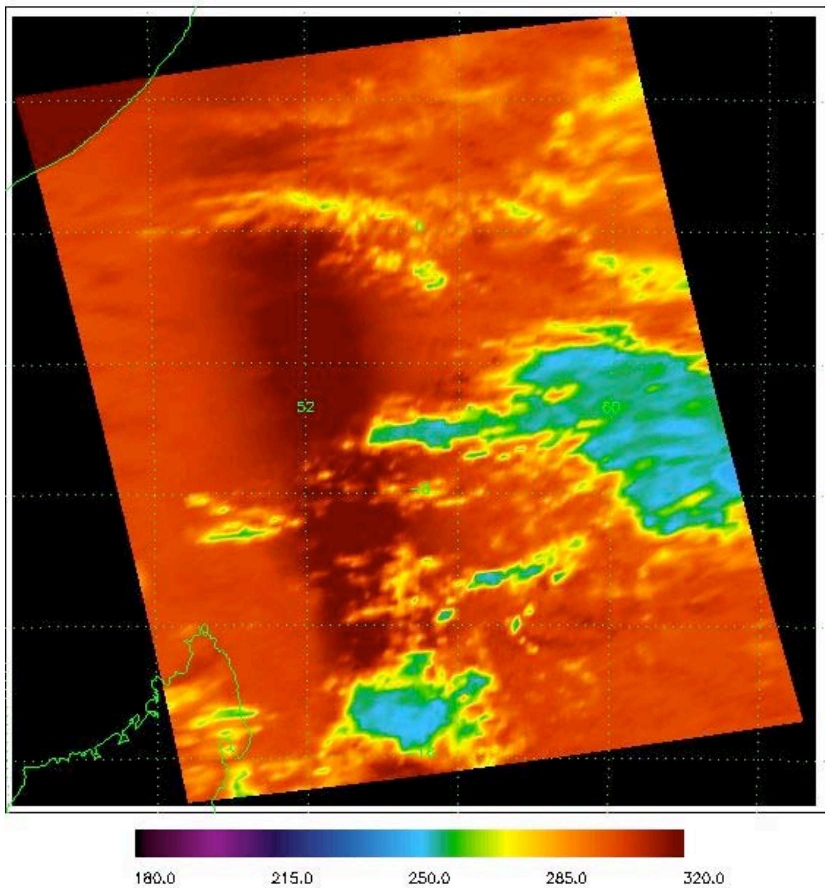
Scatter diagram of PC Score vs. Longwave Rdiff, a measure of C_{ij}

Difficult Cases for Regression -- Sun Glint

PC Score



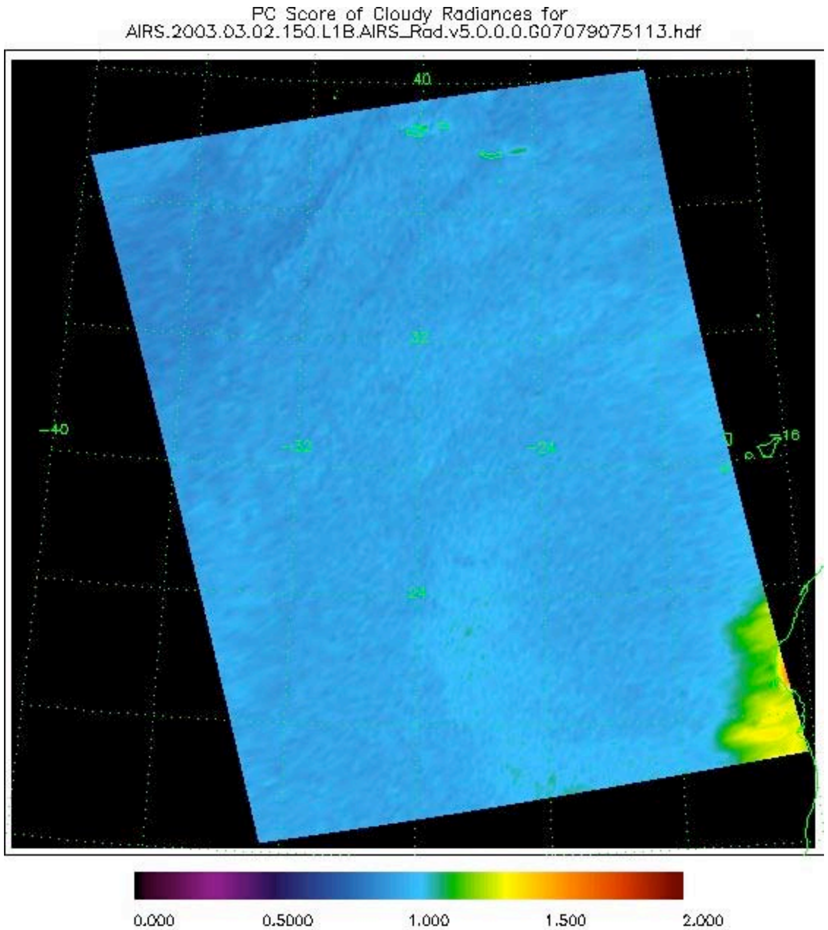
2616 cm^{-1} Br Temp



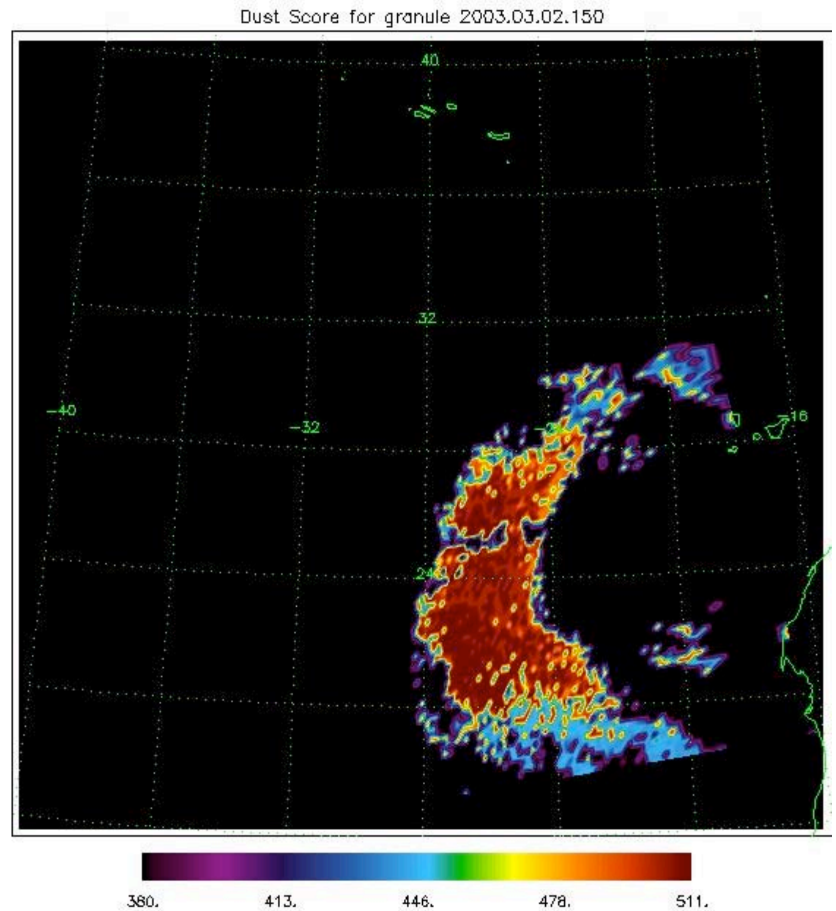
Granule 99 of March 2, 2003

Difficult Cases for Regression -- Dust

PC Score

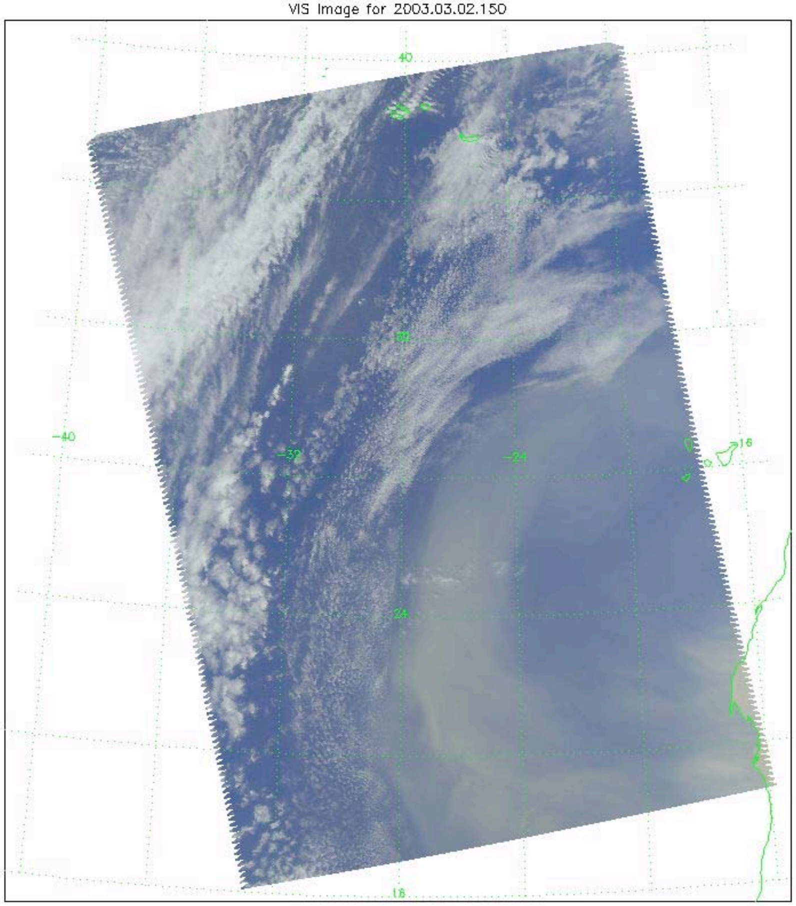


Dust Score



Granule 150 of March 2, 2003

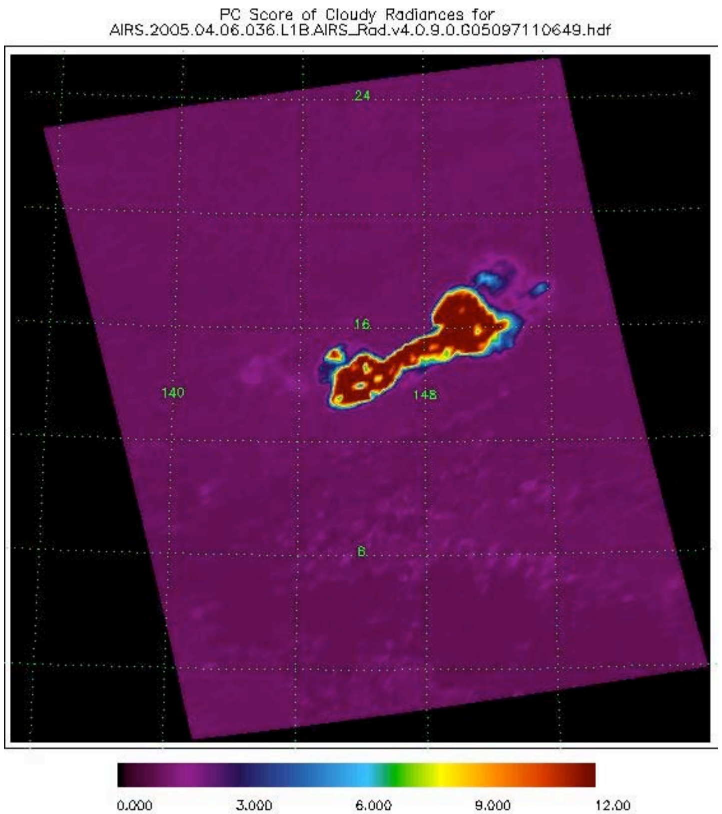
Difficult Cases for Regression -- Dust (cont)



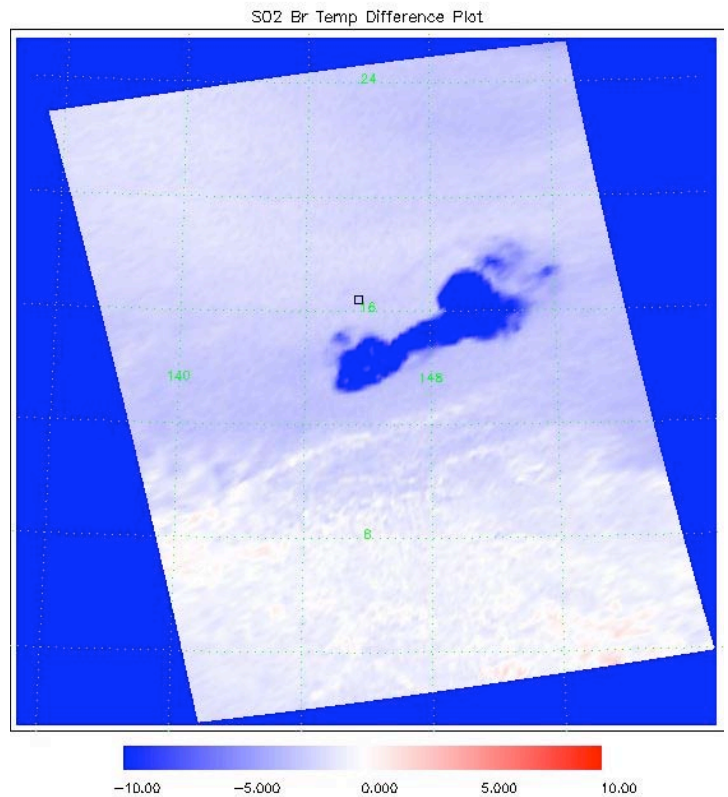
Dust Score Misses Some Dust

- **Dust plume near nadir is detected by dust score**
  - Only marginally high PC Score
- **Dust plume near the southeastern corner of granule is missed by dust score.**
  - Large PC Score

Difficult cases for Regression -- SO_2



PC Score

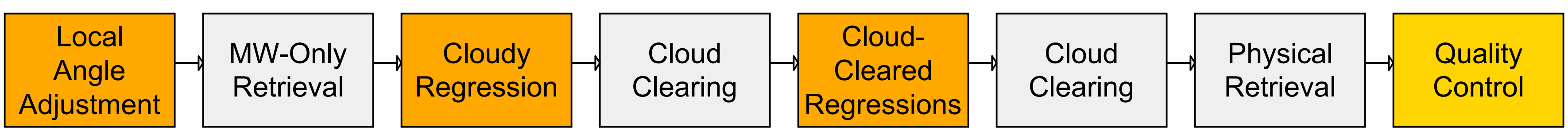


SO_2 Br Temp Diff

- **Volcanic plume from Anatahan**
- **Granule 36 of April 6, 2005**

Placement of Regressions

- **AIRS retrieval includes these key regression steps:**
  - Local angle adjustment
  - 1st guess cloudy regression
  - Cloud-Cleared profile regression
  - Cloud-Cleared surface property regression
- **Cloud Clearing plus physical retrieval as last retrieval step should attenuate the impact of upstream regressions**
- **Quality control mixes in regression results**
  - Uses PC scores
  - Uses differences between results of regressions and physical retrieval



Channel Filling

- Radiances of channels needed by regression are replaced with synthetic radiances when those channels are not considered useable.

- Overzealous standards have led to too many channels being filled. This will be reduced in version 6.

- The current channel filling algorithms are not optimal. They will be updated in v6.

- See details in backup material.

AIRS Channel Filling -- First 4+ Years

Year	Number of Channels Routinely Filled (out of 1680)
Late 2002-2003	1 - 7
2004	3 - 7
2005	2 - 14
2006-Early 2007	6 - 16

Spot check of 1st scan of granule #120 of selected focus days

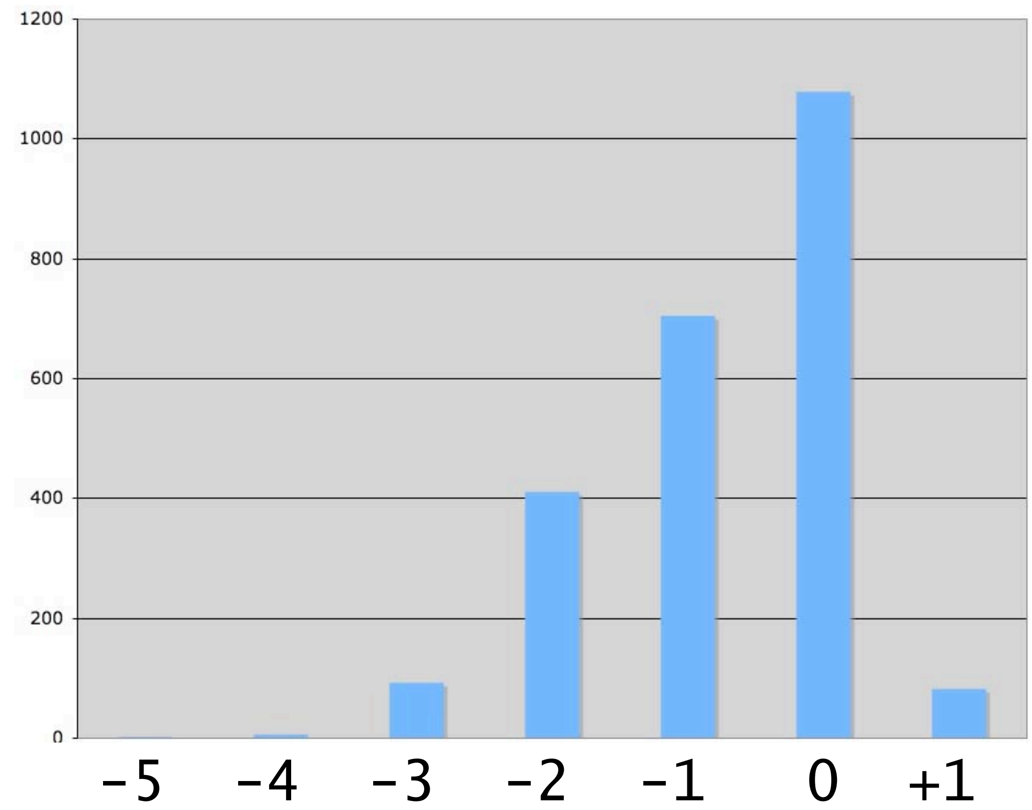
Tests of Channel Filling

- **These tests selectively block channels in Level-1B radiances and look at results of full retrieval**
  - Test 1
    - One granule is run 2378 times, with one channel flagged bad each run
  - Test 2
    - Data for 2002-09-06 (focus day 3) was run twice and results were compared:
    - 1st run is exactly released v5.0 product
    - 2nd run uses the v5.0 algorithm but the input is changed -- 15 channels which are not used on 2005-01-30 are flagged bad in the Level-1 input to retrieval

Results of Channel Filling Test 1

- **Histogram of change in yield of retrieval-type 0 (out of ~1000)**

Filling a single "average" channel causes yield to drop by ~0.1%



Results of Channel Filling Test 1

Channels with the largest effect on total cloudiness -- bias in *mean* cloudiness over an entire granule

Chan #	Freq cm^{-1}	CC 1	CC 2
2109	**2388.2**	**17 %**	**8 %**
2110	**2389.1**	**21 %**	**7 %**
1876	**2182.3**	**-7 %**	**2 %**
1871	**2186.9**	**-10 %**	**2 %**

- **The worst channels to lose are those near gaps in the regression set.**
  - Planned changes to the filling algorithms will fix this.
- **Physical retrieval reduces but does not eliminate the effect.**
- **Fortunately none of these channels have been lost.**

Results of Test 2

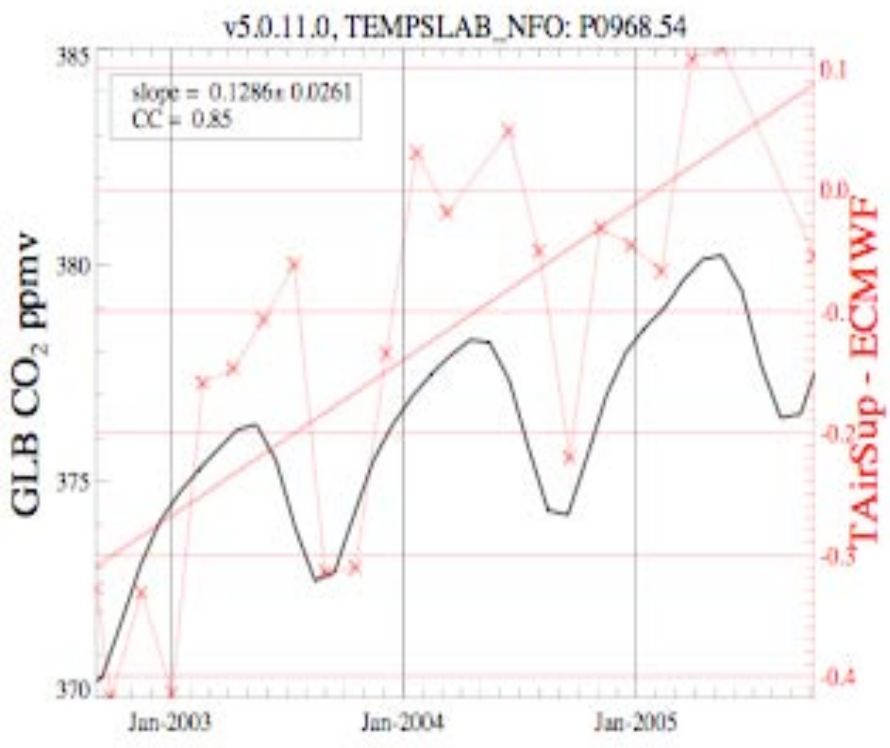
- **Differences caused by filling could be interpreted as climate trends**

Field	Change	Spurious Trend / 4 yrs
TSurfStd	+0.010 K	2.5 mK/yr warming
TSurfAir	-0.012 K	3 mK/yr cooling
TSurf1Ret	+0.026 K	6 mK/yr warming
O_3 yield	0.4% decrease	0.1 % /yr decrease
Initial_CC_score	0.0016	0.0004 /yr increase
nchan_big_ang_adj	-0.02	0.5%/yr decrease

- **Channel filling is not the main source of the spurious trends identified by Divakarla & Hearty (~100 mK/yr)**
- **But channel filling error is significant at the level of climate: ~10 mK/yr**
- **Effect on outliers not yet evaluated**

CO_2

- CO_2 changes with seasonal cycle and secular trend
- AIRS Level-2 trends resemble change in CO_2
- R-Branch CO_2 trend equivalent to ~50 mK/yr (per HHA)
- V5 regressions were trained on early mission data when CO_2 was lower
- V6 regressions will be trained to compensate



Hearty

Plans for v6

- **Limit use of regression**
- **Train regressions to handle the entire mission**
- **Improve channel filling**

V6 Plans -- Limit Use of Regressions

- **Angle Adjustment**
  - Evaluate simple training mean adjustment, segmented by angle and perhaps day/night, latitude, land/sea, solar zenith angle, etc. but not radiances
  - Joel Susskind is exploring 3x1 retrieval with no local angle adjustment

- **Cloudy regression, clear regression, surface regression**
  - Evaluate complete removal
    - MW first guess instead of cloudy regression
    - Mini-physical retrieval instead of clear regression
    - Surface emissivity guess from MODIS historical or climatology + MW for snow detection
  - Remove PC scores and differences of regression results from other retrieved states from error estimation and quality control

V6 Plans -- Train Regressions to Handle Entire Mission

- **Representative training sets to be selected by AIRS project and NOAA science team member**
  - Will be isolated from test data
- **Revisit channel selection to use only channels sensitive to target species**
- **May need multiple epochs to cover the entire mission**
  - This increases effort
  - Smooth transitions to avoid step functions at epoch boundaries
  - Must be careful of changes in models
- **Evaluate making regressions aware of CO_2**
  - Use time as a predictor
  - Use modeled CO_2 as a predictor

V6 Plans -- Improve Channel Filling

- **Will not fill as many channels**
  - Use values when noise level increases but is still under ~1 K
  - Eliminate lower limit of 150 K on cloud cleared radiances

- **Improve channel filling algorithms**
  - Evaluate alternate algorithms
    - First guess:
      - From all nearby channels, not just those used in regression
      - From channels selected for high correlation
      - From computed radiances based on the current state
    - Multiple passes through PC

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Backup Slides

California Institute of Technology

Jet Propulsion Laboratory

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Cloudy and Clear Profile Regressions, Surface Regression

- **Cloudy regression was added in v5 as a partial replacement for MW-only retrieval**
- **It is used as a first guess of profile into the first iteration of cloud clearing**
- **Clear profile regression runs after first cloud clearing**
  - It provides a profile for use in the second iteration of cloud clearing.
  - Its fine vertical structure is preserved in physical retrieval retrieval
- **Surface regression runs right after clear profile regression.**
  - It provides an estimate of surface spectral emissivity used in second cloud clearing
  - Its fine structure is preserved through physical retrieval

Why Channels Are Filled

- **Noise levels of individual channels can change**
- **Some detectors have experienced significant long-term changes in noise levels**
    - See presentation by Denis Elliott
- **Other channels experience occasional changes in dark current ("pops") or transient high-noise events**
- **2-point calibration prevents any changes in bias -- only noise level changes**

Why Channels Are Filled

- **Training a regression implicitly makes it expect a given noise level -- it weights lower-noise channels more heavily**
- **Channels experiencing significantly higher noise levels than they had in the training set are not used as input to regressions**
- **But the regressions need input for all channels.**
- **Channel filling algorithms replace the radiance of a missing channel with a predicted radiance**
- **But note: the current screening of channels appears to be too strict, leading to too much channel filling. Version 6 will depend less on this method.**

Channel Filling

- **Different channel filling algorithms are used in different regressions.**
- **Local angle correction**
  - Initial radiance for filled channels set to training mean
  - PC scores calculated from radiances (including filled)
  - New radiances calculated from PC scores
- **Clear and cloudy profile regressions + surface regression**
  - Initial radiance for filled channels set to match mean of differences from training mean of radiances of 10 spectrally close* channels used in regression
  - PC scores calculated from radiances (including filled)
  - New radiances calculated from PC scores
- *** Channels selected may not be truly spectrally close because of gaps in the spectral coverage**

Pitfalls of Channel Filling

- **Filled values will not have correct noise characteristics**
- **Filled values will tend toward a training mean**
  - Output will tend to be correct in an average sense but extreme cases will be curtailed
- **Because the number of channels filled tends to increase with time, results will tend to systematically exclude extreme cases with time**

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Examination of PC Score

Sung-Yung Lee

California Institute of Technology
Jet Propulsion Laboratory

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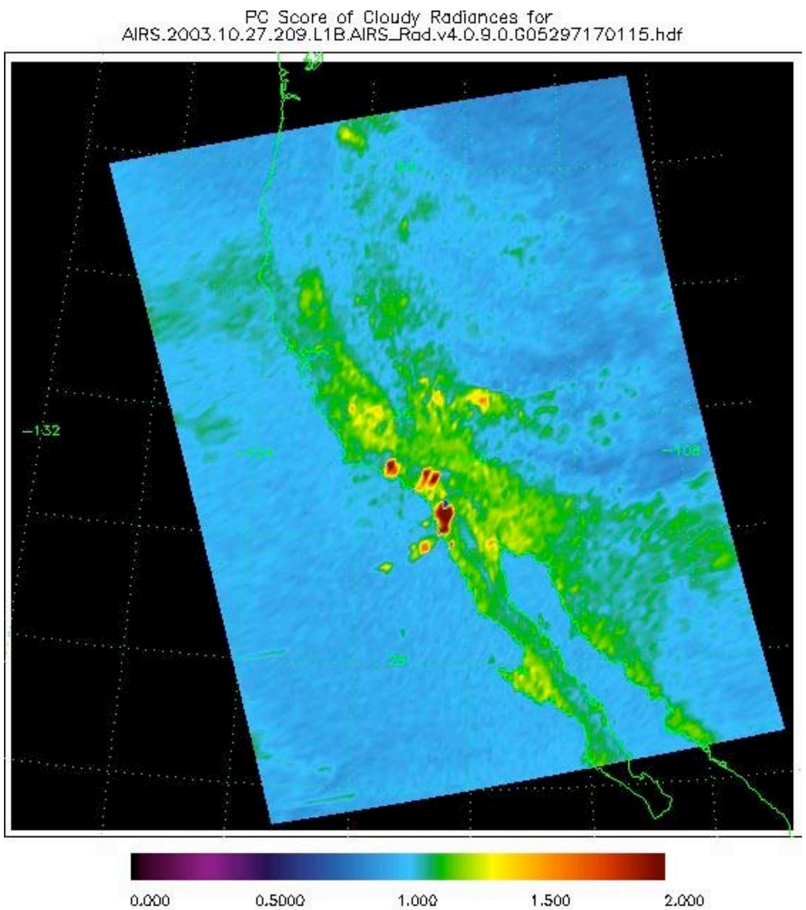
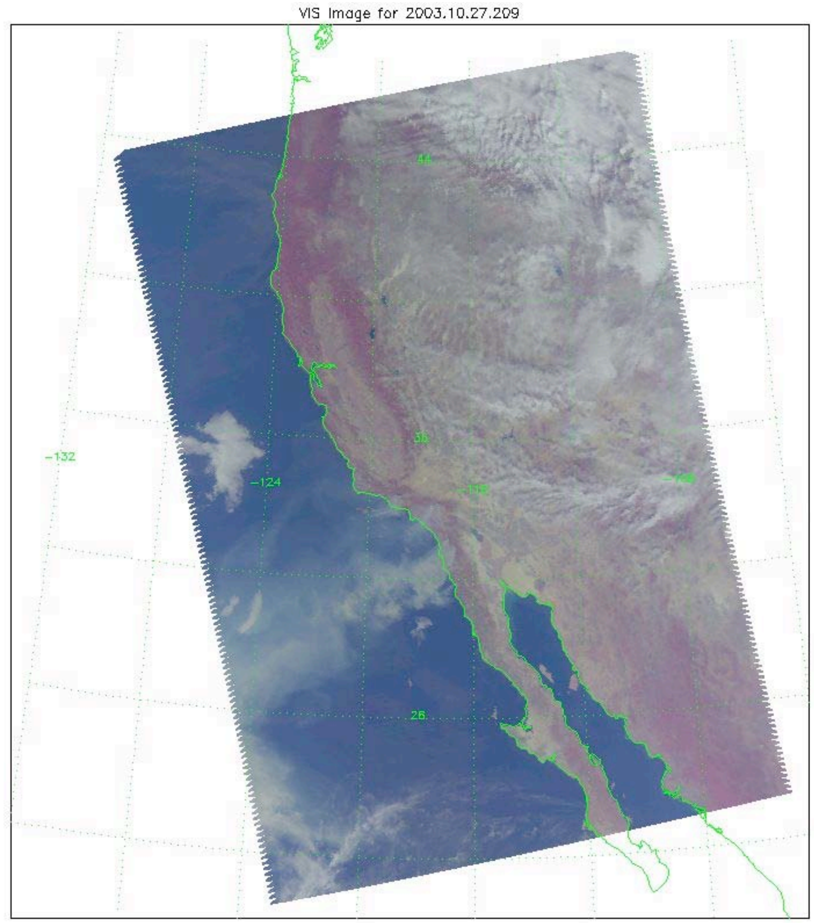
Principal Component Score

- **M Goldberg (NOAA/NESDIS) developed algorithm to compress AIRS radiances as coefficients to principal components or eigenvectors.**
  - The principal components are computed from the radiances normalized by the channel noise, NeN.
  - Many of the channels used in the PC analysis became noisy over time
    - 25 channels as of mid-2007.
    - Early report claims the channel filling algorithm is reliable with fewer than 20 bad channels.
- **The Principal component scores is defined to be the residual error of the reconstructed radiances, in the unit of NeN.**
  - PC score of AIRS observed radiance is normally around 1.
  - PC scores are large when C_{ij} becomes an issue
  - PC scores are large over sun glint area and over brush fire
  - PC scores are large over “some” dust, but not all.
- **The initial regression algorithm of AIRS uses the principal components.**
  - It is applied to cloud cleared radiances.
  - The PC score is used as a measure of quality of cloud clearing.
  - Currently retrievals are rejected when PC score is larger than 4.

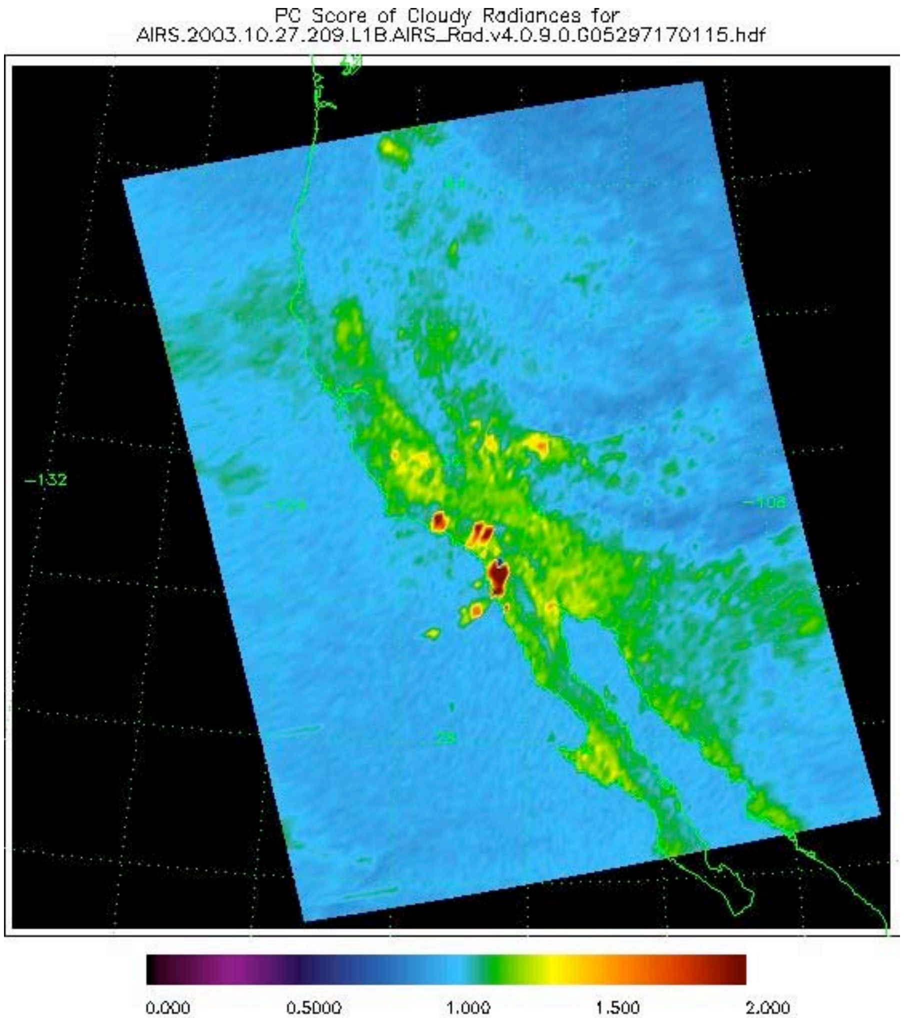
High PC Scores over Brush Fire





- **Granule 209 of Oct 27, 2003**

Granule 209 of Oct 27, 2003



- **There are many brushfires burning in Simi Valley, Mt Baldy, Arrowhead, Cleveland Forest and San Diego.**
- **CO plume over ocean also has high values of PC score**

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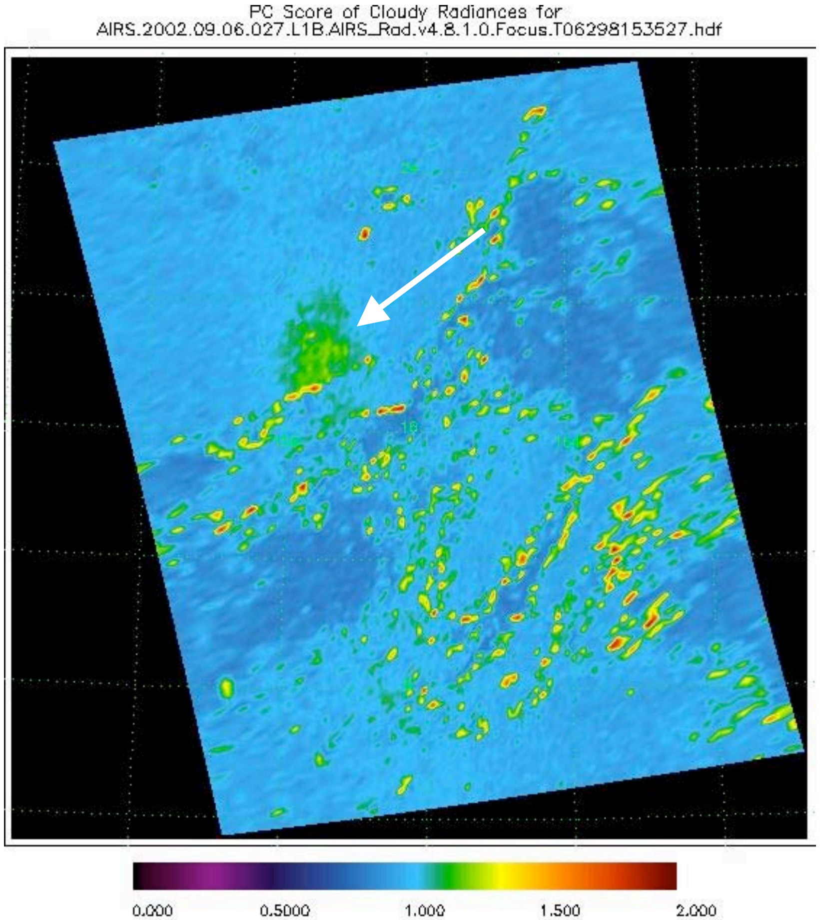
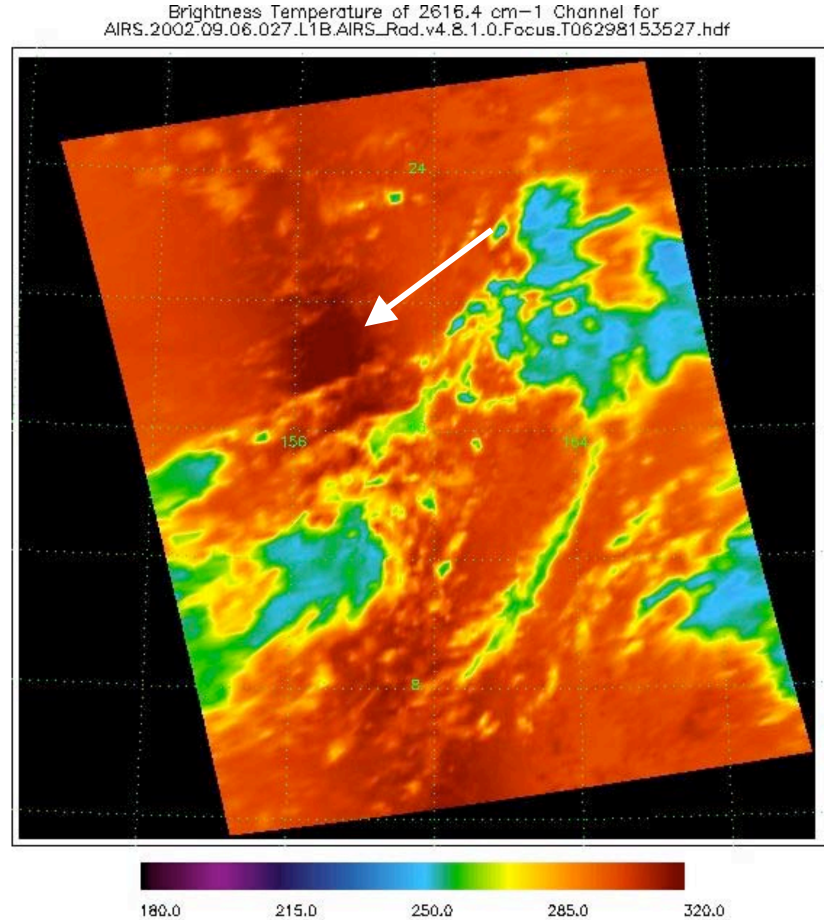
Granule 27 of Sept 6, 2007



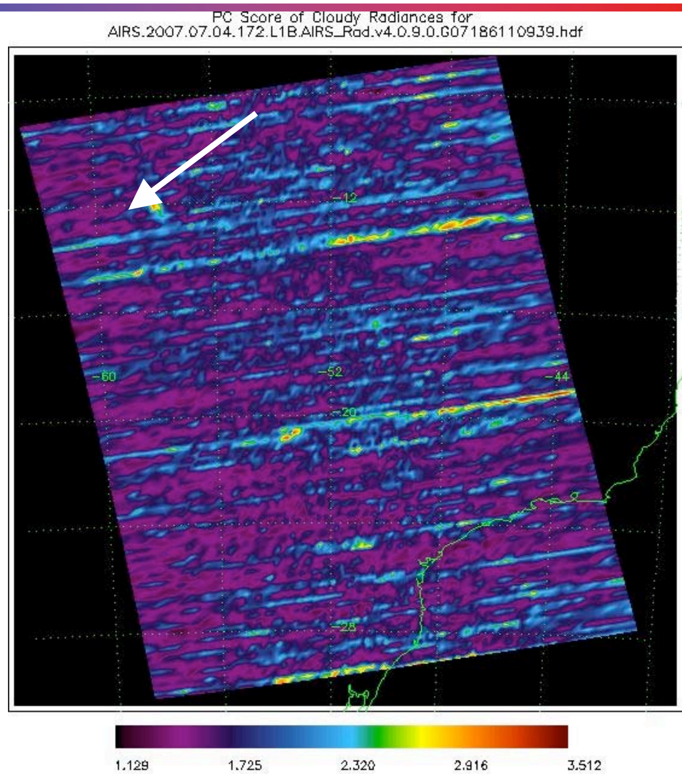
PC Score



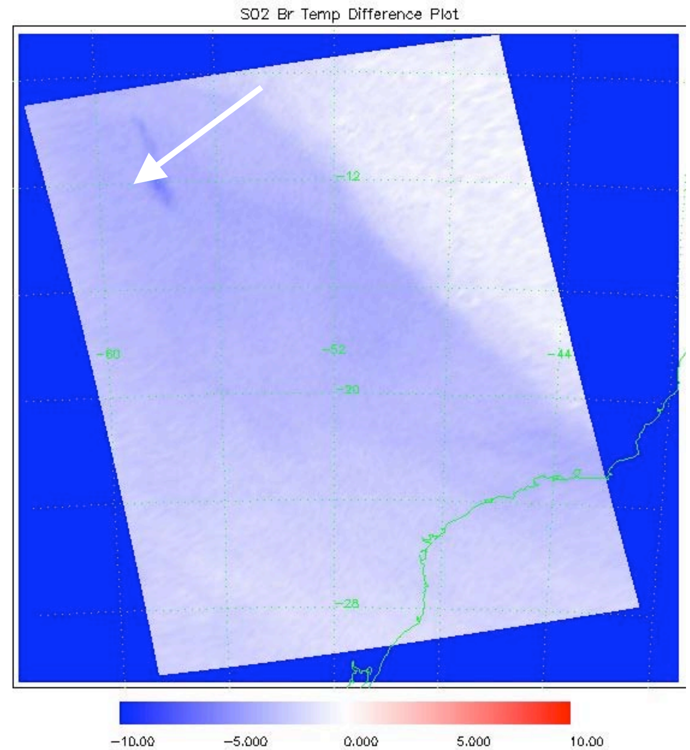
Tb 2616 cm^{-1}

- **Clear sun glint area has higher value of PC score**

Granule 172 of July 4, 2007



PC Score



SO_2 Br Temp Diff

- **PC score (this version does not fill bad channels) degraded due to channel losses over time (29 bad channels in this granule)**
- **SO_2 plume (yet unknown source) is noticeable even in this figure**

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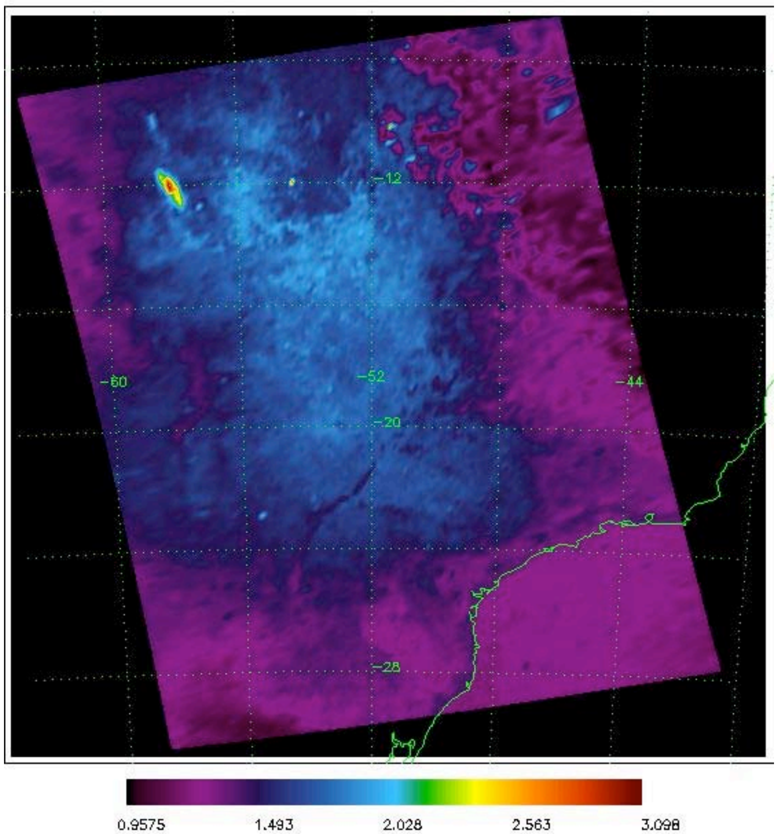
Granule 172 of July 4, 2007 (Continued)

PC Score of Cloudy Radiances for
AIRS.2007.07.04.172.L1B.AIRS_Rad.v4.0.9.0.G07186110939.hdf



- **Bad channels are filled using algorithm developed for local angle correction**
  - Fill bad channels with training mean
  - Reconstruct radiances using PC analysis
  - Fill bad channels with reconstructed radiance
  - Do another PC analysis to reconstruct
  - Compute PC score based only on good channels
- **The filled PC score clearly shows SO_2 plume**

Contingency -- Use Level-1C

- **Level-1C product will contain radiances resampled to a fixed grid.**
  - This eliminates a minor issue with regressions
- **Level-1C may also include filled values**
  - This would eliminate the need for channel filling in Level-2
  - Level-1C now would be responsible for avoiding the pitfalls of channel filling
- **Following this path for version 6 brings scheduling complications:**
  - Define Level-1C algorithm
  - Implement Level-1C
  - Run Level-1C on large dataset
  - Test Level-1C
  - If Level-1C acceptable, retrain all Level-2 regressions
  - If Level-1C is not acceptable, do something else in Level-2
  - Test Level-2